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2019 – Issue 49

Saudi Arabia oil & gas

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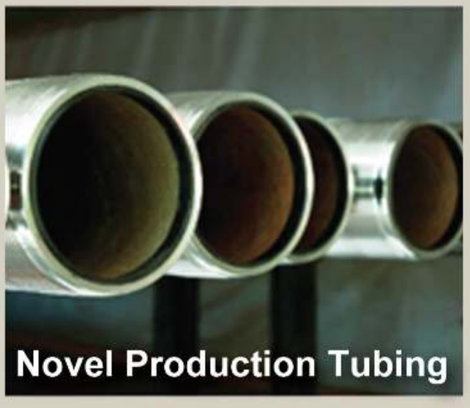
Inside

تداول
Tadawul

Aramco Floats to Top



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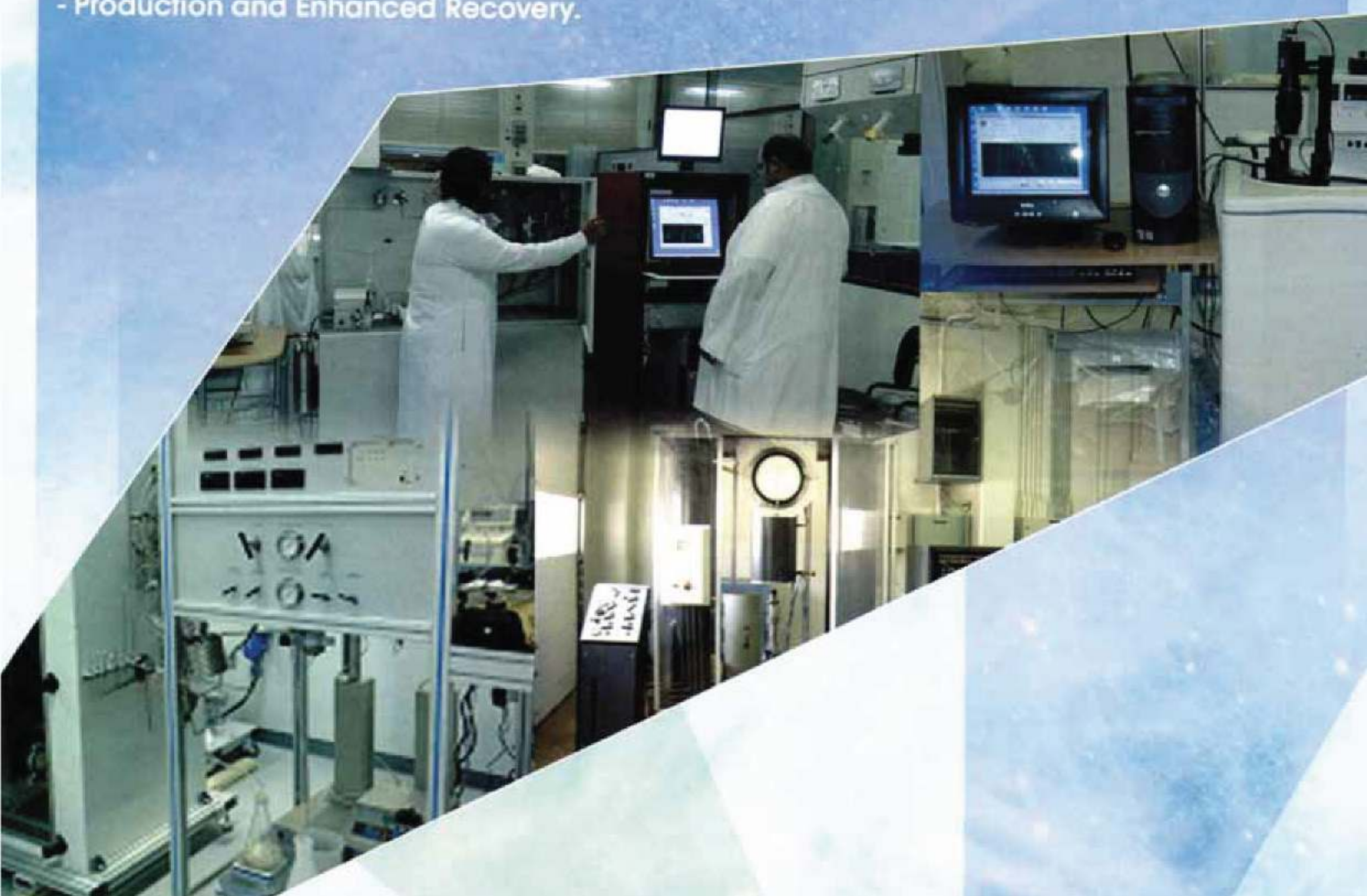
Oil and Gas Research Institute

Hydrocarbon resources (crude oil and gas) are the main source of world energy, and as the international demand increases, the technical challenges increase to meet that demand. Hydrocarbon production optimization at minimum cost and the need to serve the national petroleum industry has been the driving force behind the establishment of the Oil and Gas Research Institute (OGRI) at King Abdulaziz City for Science and Technology (KACST). OGRI is a governmental research and development entity. Its applied research activities concentrate on the upstream sector of the petroleum industry. Fields of interest cover most of the petroleum science and engineering aspects through four main divisions:

- Reservoir Characterization and Numerical Simulation,
- Drilling Engineering,
- Rock Mechanics,
- Production and Enhanced Recovery.



Services Provided

Service	Techniques
CONVENTIONAL CORE ANALYSIS	➤ Helium Porosity (Ambient Conditions) ➤ Gas Permeability & Porosity (Low and Reservoir Overburden Stress) ➤ Klinkenberg Correction ➤ Liquid Permeability (Reservoir Conditions)
SPECIAL CORE ANALYSIS (SCAL)	**CAPILLARY PRESSURE TESTS** ➤ Centrifuge Techniques (Reservoir Conditions) ➤ Low and High Pressure Mercury Injection and Withdrawal Technique ➤ Pore Size Distribution (PSD) **RELATIVE PERMEABILITY MEASUREMENTS** ➤ Unsteady State Flooding Technique (Reservoir Conditions) ➤ Centrifuge Technique (Reservoir Conditions) **WETTABILITY TESTS** ➤ Centrifuge USBM Method ➤ Contact angle Measurement (Ambient and Reservoir Conditions) ➤ Interfacial Tension Measurements **PETROGRAPHIC SERVICES** ➤ Sieve Analysis ➤ Particle Size Analysis ➤ Thin section
RESERVOIR FLUID ANALYSIS	➤ Interfacial & Surface tension ➤ Gas and Gas Condensate Viscosity ➤ Refractive index and pH ➤ Contact angle
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EPRASHEED
signature series

2019 - ISSUE 49
Saudi Arabia oil & gas

Saudi Arabia Oil & Gas (Print) ISSN 2045-6670
www.saudiarabiaoilandgas.com
Saudi Arabia Oil & Gas (Online) ISSN 2045-6689

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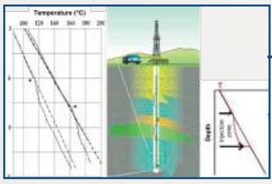

Cover Photo: Courtesy of Saudi Aramco King Abdulaziz Center for World Culture. The Center brings together educational, cultural, artistic and scientific offerings under one roof.

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Contribute to Saudi Arabia Oil & Gas In Issue 50 and Beyond

EPRasheed encourages editorial submissions on the topics outlined in the editorial calendar. This can provide your company with the opportunity to communicate EP technology to the wider oil and gas community.

Please send abstracts or ideas for editorial to wajid.rasheed@eprasheed.com. Preference is given to articles that are Oil Company co-authored, peer reviewed or those based on Academic research.

Editorial Calendar 2020

February - Issue 50	May – Issue 51	August – Issue 52	November – Issue 53
Materials Closing date - Jan 15	Materials Closing – Apr 15	Materials Closing – July 15	Materials Closing – Oct 15
o Remote Operations o Intelligent Completions o Digitalization o Production o Artificial Intelligence	o Cementing o Drilling & Completion Fluids o Rotary Steerable Systems o Complex Wells o Geophysical	o Seismic o Reservoir Visualization o Remote Operation Centres o Advances in Drill-Pipe o Drill-Bit Technology o Zonal Isolation (incl. Packers, Multi-Zone Completions) o Carbonate Reservoir Heterogenity	o Reservoir Characterization o Drilling Optimization o Formation Evaluation o Wellbore Intervention o Casing While Drilling o Seismic
GEO 2020 March 3 - 5, 2020 Manama, Bahrain	EAGE SPE EUROPEC Jun 9-12, 2020, Rome, Italy	ONS Offshore Northern Seas Aug 26-29, 2020, Stavanger, Norway	ADIPEC - Abu Dhabi International Petroleum Exhibition and Conference Nov 3-6, 2020
IPTC* 13–15 January 2020 Dhahran EXPO Kingdom of Saudi Arabia	SPE Middle East Colloquium on Petroleum Engineering, March 30 - April 2, Dubai, UAE		World Petroleum Congress Houston, Texas, USA, December 6-10, 2020
	SEG* Artificially Intelligent Earth Exploration Apr 19-21 Muscat, Oman		

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SPECIAL PUBLICATIONS

Tadawul Celebrates the Listing of Aramco's Shares on its Main Market

RIYADH, 12 December, 2019

The Saudi Stock Exchange (Tadawul) celebrated the listing of Saudi Aramco's shares on its Main Market. The ceremony was held at the Fairmont Hotel in Saudi Arabia's capital, Riyadh, in the presence of HE Yasir Al-Rumayyan, Chairman of Aramco; Sarah Al Suhaimi, Chairperson of Tadawul; Eng. Ameen Al Nasser, CEO of Aramco; Eng. Khalid Al Hussan, CEO of Tadawul; and other high-ranking officials.

Eng. Khalid Al Hussan commented: "The Aramco listing is a significant moment in Tadawul's journey and bolsters our position among international stock exchanges. It also reinforces our status as one of the largest equity markets in the world. This national achievement is testament to the effective collaboration between Tadawul, Aramco and the Capital Market Authority of Saudi Arabia."

He added: "Today is a momentous occasion as the world turns its attention to Saudi Arabia for the largest IPO in the history of global capital markets. We would like to congratulate Aramco on their successful IPO and express our pride that Tadawul was chosen as the venue for the listing of its shares."

Tadawul successfully delivered market capacity and trading system upgrades over the past two years to accommodate the significant increase in trading activity and potentially large IPOs associated with listings like Aramco's. This has contributed to cementing Tadawul's reputation as a world-class stock exchange from both a technology and infrastructure perspective, in line with international best practices.

Today's event marks a major milestone in the history of the Saudi capital market. Tadawul's total market capitalization increased from USD 509 billion to USD 2.3 trillion, boosting the exchange's position from the top 10 largest stock exchanges in the world.

Eng. Khalid Al Hussan, CEO of Tadawul commented:

"The Aramco listing is a significant moment in Tadawul's journey and bolsters our position among international stock exchanges. It also reinforces our status as one of the largest equity markets in the world. This national achievement is testament to the effective collaboration between Tadawul, Aramco and the Capital Market Authority of Saudi Arabia."

Saudi Arabian Oil Company (Saudi Aramco): Listed on Tadawul

RIYADH, December 11, 2019

The Saudi Arabian Oil Company ('Saudi Aramco' or 'the Company') has officially listed on the Saudi Stock Exchange (Tadawul) today, marking the successful Initial Public Offering ('IPO') of the Company.

Saudi Aramco's stock symbol ticker is (TADAWUL: ARAMCO) and its shares began trading at SAR32. The Offering process, which concluded on December 4, generated subscriptions by Institutional and Individual Subscribers of SAR446billion / USD119 billion, or 4.65 times the total Offer Shares (assuming no exercise of the Purchase Option).

The Offering attracted more than 5 million subscribers. The Kingdom of Saudi Arabia sold 3 billion shares (excluding any exercise of the Purchase Option), equivalent to 1.5% of the Company's share capital. Priced at the top of the indicated range, the Offering generated proceeds of SAR96.0 billion / USD25.6 billion (assuming no exercise of the Purchase Option), making it the world's largest IPO.

Saudi Aramco's listing and share trading debut was marked by a symbolic ringing of the Tadawul bell by His Excellency Yasir Othman Al-Rumayyan, Chairman of the Board of Directors, and Amin H. Nasser, President and Chief Executive Officer.

Celebrating and sharing the historic milestone were Saudi Aramco's Board of Directors and Executive Management team, Tadawul's Chairperson, Sarah Al-Suhaimi, and Chief Executive Officer, Khalid Abdullah Al Hussan, as well as other dignitaries from the Government of the Kingdom of Saudi Arabia.

His Excellency Yasir Othman Al-Rumayyan, Chairman of the Board of Directors of Saudi Aramco, said: "This is a proud and historic moment for Saudi Aramco and our majority shareholder, the Kingdom, as Saudi Aramco begins life as a listed company on Tadawul, together with all our new individual and institutional shareholders here in the Kingdom, in the region and around the world."

"My focus, and that of our Board of Directors, is to work in the interests of all shareholders, guiding Saudi Aramco as it continues to fulfil its vital role in global energy supply, whilst striving to create long-term value to benefit all shareholders. Our approach is underpinned by a disciplined capital allocation process and a highly experienced senior management team."

"Today's milestone underlines the Kingdom's commitment to nurturing a strong capital market and demonstrates further significant progress in delivering Vision 2030 -the Kingdom's transformation, economic growth and diversification program that continues with pace and determination." Mr. Amin H. Nasser, President and Chief Executive Officer of Saudi Aramco, said:

"Saudi Aramco's trading debut on Tadawul marks the completion of the world's largest IPO and the beginning of an important new chapter in our history. We are a company with a rich history here in the Kingdom dating back to 1933. Our success since that time is based on the strong foundation and values created by our pioneers and reinforced by subsequent generations of Aramcons. Today, that foundation, those values and this legacy are being carried forward by my colleagues around the world."

"We believe the demand from a broad base of individual investors and such a wide range of institutions reflects trust in our long-term strategy and our vision to become the world's pre-eminent integrated energy and chemicals company, operating in a safe, sustainable and reliable manner."

"Building on our low-cost production and our reliable supply of low carbon-intensity crude oil to our customers, we will remain focused on providing our shareholders with resilient value creation through crude oil price cycles."

King Salman Celebrates Sustainability

RIYADH, November 13, 2019

King Salman ibn 'Abd Al-'Aziz Al Sa'ud, Custodian of The Two Holy Mosques, presents trophies to winners of the King Khalid Award, including Saudi Aramco president and CEO Amin Nasser. The company was given the award for efforts by the Yanbu' Refinery Department in implementing innovative practices to enhance sustainability.

Under the patronage of the Custodian of The Two Holy Mosques, King Salman ibn 'Abd Al-'Aziz Al Sa'ud, Saudi Aramco has been awarded the King Khalid Award 2019 for Corporate Sustainability.

The Yanbu' Refinery Department (YRD) won top honors in this category and was recognized during the award ceremony in Riyadh on Monday.

"I feel very proud for being honored by King Salman ibn 'Abd Al-'Aziz Al Sa'ud for Saudi Aramco's Yanbu' Refinery," said Amin Nasser, Saudi Aramco president and CEO. "It is a badge of honor to every employee in the company especially that the essence of this award revolves around corporate sustainability which is considered more than ever to be a pivotal subject in energy transformation during the 21st century.

"Saudi Aramco is an international leader in the oil and gas industry within this field, and this reflects on the company's excellence, and its transformation into the world's biggest integrated company in energy and chemicals, which constantly contributes in supplying the world with needed energy for the continuity of its prosperity, in addition to increasing its economic growth," Nasser added.

Innovation driving excellence at Yanbu' Refinery

Yanbu' Refinery earned the first place recognition in the Corporate Sustainability category by distinguishing itself for the innovative incorporation of sustainability in its practices, as well as operations on social, economic, and environmental levels in the Kingdom.

Nasser noted that Yanbu' has been one of the company's local refineries with a strategic importance since its establishment in 1983. With a processing capacity of 250,000 barrels of crude oil per day, it is efficiently led and operated by a highly qualified Saudi workforce. It is considered a vital artery in supplying the local market with petroleum products.

Yanbu' Refinery is also an exceptional example of the oil and gas refining systems in the Kingdom, as it has attained groundbreaking levels in efficiency, reliability, and safety in an economical and sustainable way.

"This award reflects the commitment and dedication of all leaders and staff at Yanbu' Refinery in achieving the goals of Saudi Aramco's Operational Excellence program, which has led Yanbu' Refinery to win multiple awards throughout

Through King Khalid Award

> I feel very proud for being honored by King Salman ibn ‘Abd Al-‘Aziz Al Sa’ud for Saudi Aramco’s Yanbu’ Refinery.” “It is a badge of honor to every employee in the company especially that the essence of this award revolves around corporate sustainability which is considered more than ever to be a pivotal subject in energy transformation during the 21st century.
>
> Said Amin Nasser, Saudi Aramco president and CEO.

Saudi Aramco, across the Kingdom, and around the world in the past few years, in the fields of energy, safety, environment, cybersecurity, and social responsibility, in addition to sustainability.

“It is considered an exemplar of Saudi Aramco’s facilities that implement sustainability in their core operations through the use of low-carbon energy solutions, following regulations and standards in operations, maintenance, and innovation fields,” said Nasser. “This is in addition to raising the employees’ awareness on the importance of a commitment to environmental standards, and successfully implementing social, economic, and environmental initiatives such as the use of advanced technology toward creating a clean energy industry.”

Nasser also highlighted YRD’s restoration of natural habitats, which are essential for marine organisms and birds, through the planting of a mangrove forest something that is considered to be the most important natural basin for the absorption of carbon dioxide.

“It is also a platform for Saudis to gain the necessary skills that will enable them to work in the oil and gas industry through training institutes all while still maintaining outstanding safety performance with no incidents and no injuries,” he said.

Relying on our people, our processes, and the spirt of R&D

Nasser credited YRD’s win in the Corporate Sustainability category to the application of development initiatives that includes many aspects, such as:

Employee capabilities and their knowledge of the company’s strategies

Identifying best practices locally and globally through building a local networking platform to exchange expertise and overcome challenges incorporating social responsibility and citizenship adopting the spirit of research and development.

Nasser expressed his pride and happiness with an award that comes from the prestigious King Khalid Foundation, adding that the award will present a motivating factor for employees and departments toward excellence and creativity.

Nasser also thanked HRH Prince Faisal ibn Khalid ibn ‘Abd Al-‘Aziz Al Sa’ud (King Salman’s consultant and the Chairman of the Board of Trustees of the King Khalid Foundation), who has worked diligently to encourage private businesses through this award, enabling them to play a crucial role in the development of the Saudi community.

About the King Khalid Foundation

The King Khalid Foundation is a platform to celebrate, honor, and recognize enterprises that have created a competitive advantage through the innovative use of sustainable business practices and in doing so, have helped spur Saudi Arabia’s social, economic, and environmental progress. The nominees are selected on the basis of their positive contribution in social challenges, as well as social sustainability.

These awards enable others who strive to achieve economic growth to follow the same path.

Remarks by Amin H. Nasser, Saudi Aramco Council (WEC) Congress

ABU DHABI, United Arab Emirates, September 10, 2019

"Your Royal Highnesses, Your Excellencies, distinguished guests, ladies and gentlemen, good morning.

I would like to thank our Emirati hosts for their hospitality; and the World Energy Council for organizing yet another outstanding event.

Throughout our history, our competitive edge can be summarized in four core attributes: resource abundance, safe production, reliable supply, and affordability.

But meeting society's expectations of sustainable energy will require a fifth.

Quite simply, our products need to be much cleaner.

This will be my main focus this morning.

But let me start with the undeniable link between our first four attributes and global economic development. To begin with, by ensuring access to ample energy, our industry continues to power economies and lift billions out of poverty.

Next, despite a variety of challenges, by making safe production and reliable supply the cornerstone of everything we do, we are trusted by our customers around the world.

Then there is affordability, and our industry truly appreciates its importance for consumers in both developed and developing nations.

But preserving our competitive advantages requires constant vigilance. Despite great progress, roughly one billion people still lack access to reliable electricity, and most of them live in sub-Saharan Africa.

Meanwhile, close to three billion people still rely primarily on unclean biomass, wood, and coal for their cooking needs, with more deaths each year from indoor pollution than HIV-Aids and Malaria combined.

And with Africa's population alone set to triple by the end of the century to over four billion people, one thing is clear: acute energy poverty will remain a huge challenge. It would be inhumane to ignore the issue, wish it away, or dismiss our industry's central role in tackling it.

We must also continuously remind all our stakeholders that we are a global industry at the cutting-edge of science, technology, engineering, and logistics, supported by a complex, global supply chain.

Even when we have genuine breakthrough moments, they take time and massive investments to commercialize and roll-out across the global energy network. In addition, all energy transitions (including this one) take decades, with many challenges along the road.

Certainly, we support the growing contribution that alternatives are making to meet rising global energy demand. But many governments are adopting energy policies that do not appear to consider all the complex aspects of global energy; the long-term nature of our business; and the need for orderly transitions…

…policies that seem to assume there are quick and easy answers to the many challenges alternatives face.

…policies that also seem to assume rapid electrification

President & CEO, at the 2019 World Energy

> The good news is that we are not starting from scratch. For example, at Saudi Aramco, our Master Gas System has ended associated gas flaring, eliminating about 100 million metric tons of CO_2 equivalent, every year since it was established in the 1970s.
>
> Our upstream carbon intensity in the Kingdom – from well to refinery gate – is one of the lowest in the world at about 10 kilograms of CO_2 equivalent per barrel of oil equivalent.
>
> Meanwhile, based on third party verification of our greenhouse gas emissions, our methane intensity last year was just 0.06%, which is also one of the lowest in the industry. This is especially important given that methane gas is 80 times more harmful to global warming in the first two decades after its release compared with CO_2.

of transport, overlooking the issue of clean electricity and a life-cycle measurement of greenhouse gas emissions…

…and policies that will cost tens of trillions of dollars, with the burden often falling on those who can least afford it…

We have already seen the impact of what I call a 'Crisis of Perception' on long-term investments; and if it continues supply shortfalls will follow as night follows day. That would hurt the competitiveness of national economies; threaten their energy security; and, potentially, create social disruptions (even in developed nations) by making energy less affordable.

The world can no longer afford such policy miscalculations. We need a major awareness campaign to remind stakeholders and energy users why oil and gas are still so essential. And since oil and gas will be at the heart of the global energy mix for decades to come, we need regulators to be policy holistic and technology agnostic.

So there is plenty of work ahead of us just to sustain our traditional strengths.

But the world still turns, and our industry's ability to turn with it is crucial.

Two hundred years ago, for example, in places like the United States and Europe, many people used indoor lamps fueled by oil from whale fat. But by the mid-1800s, following the discovery of oil, kerosene became the lighting fuel of choice.

The journalists and analysts of the day were probably going wild about peak whale demand! Kerosene was then challenged by electricity, putting the entire petroleum industry at risk.

But once gasoline was recognized as a fuel source for transport not just as a waste product we secured our own future and transformed the whole world.

I believe we are at a similar turning point today. In particular, we have heard, loud and clear, the call from stakeholders and society at large for cleaner energy.

The good news is that we are not starting from scratch. For example, at Saudi Aramco, our Master Gas System has ended associated gas flaring, eliminating about 100 million metric tons of CO2 equivalent, every year since it was established in the 1970s.

Our upstream carbon intensity in the Kingdom from well to refinery gate is one of the lowest in the world at about 10 kilograms of CO2 equivalent per barrel of oil equivalent.

Meanwhile, based on third party verification of our greenhouse gas emissions, our methane intensity last year was just 0.06%, which is also one of the lowest in the industry. This is especially important given that methane gas is 80 times more harmful to global warming in the first two decades after its release compared with CO2.

High-impact achievements like these, together with our long focus on sustainability and environmental stewardship, mean we have a good story to tell. But these are primarily stories of success inside our gates.

Is that enough to meet society's demands? The simple answer is "no".

The world faces an incredible climate challenge and we need a bold response to match. In my view, that means the entire industry must come together around a new mission beyond our gates of making oil and gas much cleaner across the full spectrum of end-use applications.

And make it our most urgent priority. Again, our industry has already made progress. In the EU, for example, over the past 30 years, there have been dramatic reductions in conventional pollutants.

Carbon monoxide from road transport has fallen by 88%; non-methane volatile organic compounds by 89%; and sulfur oxides by 99%. As for CO2 emissions, on average, new passenger cars in the EU-27 emitted about 185 grams per kilometer in 1995.

They are targeted to be roughly half those levels by 2021, thanks in part to our industry's work with the automotive industry. But all this still leaves a massive task ahead if we are to meet society's expectations.

That is why, at Saudi Aramco, we are working hard on a range of technologies with transformative potential beyond our gates.

This includes:

- advanced integrated enginefuel systems of the future, which aim to deliver greater efficiency and, at the same time, lower emissions.
- crude-to-chemicals, which has the potential to transform our industry with oil as a highly competitive petrochemical feedstock.
- We are also working on carbon-free hydrogen from oil-based feedstocks for use in multiple end-use applications.
- We aim to be world leaders in Carbon Capture Utilization and Storage once again turning what is seen today as a waste product CO2 into something valuable.
- And imagine advanced materials from oil which could be used in a range of high growth industries such as construction, housing, cars, and even the Electric Vehicles and renewables industries!

However, this new mission is a shared industry responsibility to our stakeholders, beyond generating long-term value for shareholders. Our concerted, accelerated, and visible response in all sectors should reflect that especially collective investment in practical solutions.

For example, members of our industry's Oil and Gas Climate Initiative have jointly allocated more than one billion dollars to lower the carbon footprint of the energy and industrial sectors.

Other, complementary approaches, especially coalitions with partners beyond our industry, should also be considered. Whatever the framework, it needs to be a comprehensive, industry led effort, it needs to move fast, and it must articulate clear, long-term carbon management strategies that give our stakeholders sufficient confidence in our programs.

Because there is no limit to our industry's potential if we can meet society's demand for ultraclean energy.

Ladies and Gentlemen, there is so much for our industry to be proud of.

Especially the hard work all of us have done on conventional emissions and carbon management inside our gates. But by coming together to play a transformative role beyond our gates, and making it our top priority, we can offer all five of the core attributes needed in future energy…

This is a mission critical moment. And at this latest turning point in our history we must, once again, lead the turn.

Thank you."

SPE 2019 Annual Technical Conference and Exhibition

CALGARY, CANADA, November 06, 2019

Six Aramcons took home prestigious awards from the Society of Petroleum Engineers (SPE) 2019 Annual Technical Conference and Exhibition held recently in Calgary, Canada.

The SPE is the largest individual organization serving managers, engineers, scientists, and other professionals worldwide in the oil and gas industry. Each year during its Annual Technical Conference and Exhibition (ATCE), SPE honors members whose outstanding contributions to SPE and the petroleum industry merit special distinction. Recipients of the 2019 International Awards were recognized at the annual reception and awards banquet in Calgary.

Presenting the awards was SPE president Sami A. Alnuaim, manager of Saudi Aramco's Petroleum Engineering Applications Services Department.

Saeed M. Al-Mubarak, right, accepts the Society of Petroleum Engineers Distinguished Service Award from organization president Sami A. Alnuaim. Both Aramcons have received the coveted award, with Alnuaim receiving his in 2011. The award was established in 1948.

Intelligent field expert earns vaunted designation

Taking home the SPE Distinguished Service Award was Saeed M. Al-Mubarak, a petroleum engineering consultant who has led the Intelligent Field Unit in the Production and Facility Development Department. Al-Mubarak was recognized for his "contributions to the society that exhibit such exceptional devotion of time, effort, thought, and action as to set them apart from other contributions."

In addition to intelligent fields, Al-Mubarak has led important teams, including the strategic team managing the world's largest intelligent fields. He has also worked in reservoir, production, drilling and completion, facilities, and knowledge management positions.

Alnuaim said: "On behalf of the SPE board of directors, I would like to take this opportunity to thank Saudi Aramco for supporting the active involvement of Saeed in the SPE. Member participation and leadership are important factors that enable the SPE to achieve its mission of collection, dissemination, and exchange of technical information."

Alnuaim was himself the first Saudi winner of the SPE Distinguished Service Award in 2011. The award was established in 1948.

Another recipient of the SPE Distinguished Service Award was David G. Kersey, recently retired from Saudi Aramco as senior petroleum engineering consultant in the Upstream Professional Development Center.

Kersey has been chairman of the SPE Java Indonesia and Saudi Arabia sections. He also initiated the formation of a Hawaiian SPE section. He is an SPE Distinguished Member, has been recognized three times as an outstanding technical editor, and received the Asia Pacific and Middle East regional SPE service awards.

Aramcons earn memberships

Receiving Honorary Membership was Anuj Gupta, a senior petroleum engineering consultant at the Aramco Research Center-Houston, where he conducts and leads research on simulation modeling workflows for unconventional reservoirs, an area of growing importance as Saudi Aramco increases its unconventional exploration activities in the Rub' al-Khali and the northern regions of Saudi Arabia. Gupta's research has advanced the disciplines of unconventional reservoirs, reservoir characterization, enhanced oil and gas recovery, petrophysics, and drilling.

In addition to these awardees, the SPE also awarded Distinguished Membership to the following:

- Sameeh I. Batarseh, a petroleum engineering consultant at the EXPEC Advanced Research Center
- Frank Chang, a senior research scientist at Aramco Research Center-Houston
- Kenneth Kibodeaux, a research science consultant at Aramco Research Center-Houston.

Al Saggaf touts 'Efficiency, Resiliency, and

MANAMA, Bahrain, October 10, 2019

Muhammad M. Al Saggaf speaks about developing strategies toward achieving the right balance between continued economic developments and protecting the planet during his keynote address at the Seventh Global HSE Conference and Exhibition in Bahrain.

Muhammad M. Al Saggaf speaks about developing strategies toward achieving the right balance between continued economic developments and protecting the planet during his keynote address at the Seventh Global HSE Conference and Exhibition in Bahrain last week.

Attendees of the seventh Global HSE Conference and Exhibition in Bahrain last week were told that "a strong foundation of health, safety, and environmental (HSE) protection" is a must for companies such as Saudi Aramco to maintain its social license to operate.

While finding the right balance of those factors can appear at times to be "elusive", Muhammad M. Al Saggaf, senior vice president of Operations and Business Services with Saudi Aramco, said a committed effort throughout the oil and gas industry is achievable.

"I believe anything is within our reach if we fully commit ourselves, with dedication and resilience," Al Saggaf said in delivering the keynote address at the event. And the resilience that is required, said Al Saggaf, was never more evident than last month when the company's facilities in Abqaiq and Khurais came under attack.

"Ultimately, fires that were intended to break us revealed a company far more resilient than anyone could have imagined," he noted. Al Saggaf said Saudi Aramco's resilience is built upon three cornerstones — "our dedicated and committed people … our vast hydrocarbon resources, and our world-class infrastructure."

The profound challenges that major oil and gas companies face each day demand "Efficiency, Resilience, and Sustainability," Al Saggaf noted in highlighting the theme of the conference.

Sustainability' at HSE conference

Sustainability built on safety, moral obligation

Al Saggaf talked about three co-centric circles of HSE, starting with safety, which he said is key to the sustainability of business success. "We must begin with safety, because this is the field of the most direct impact on our employees," said Al Saggaf.

"But safety is more than an investment. I believe that the safety of our employees is a contract with them whether it is explicit or implicit that we keep the workplace safe, not only because it is good for business, but because it is our moral obligation."

Another component of that moral obligation, he said, is the wellbeing of employees and their dependents. "The challenges are complex to achieve the right balance between quality and affordability … but smart companies must explore and innovate solutions, and we must be drivers of that change within our organizations."

Turning his attention to the environment, Al Saggaf said, "This tests our social responsibility toward our families, our people, and our ecosystem."

He cited Saudi Aramco examples of where that commitment is paying off. "Decades of investment in our well management capabilities and technologies have resulted in Saudi Aramco having the lowest upstream carbon intensity of any of the world's major producers. At the same time, our methane intensity is also one of the lowest in the industry."

Balancing economic and environmental concerns

Al Saggaf said a collective strategy toward achieving the right balance between continued economic developments and protecting the planet must be based on several factors, including:

- Developing rational, well-rounded policies
- Investing in the appropriate technologies
- The proper education of all stakeholders

"And we must do all of this with a high degree of transparency and openness, because the world is watching."

Technology, said Al Saggaf, is the key to solving most challenging problems faced with regard to HSE. "But we must be the drivers the adaptors and the adopters of the technologies best suited for our businesses.

"The breakthroughs of the Fourth Industrial Revolution are redefining, in real time, what is possible. But these breakthroughs require vision, and they require investment."

Al Saggaf told attendees of the conference that sharing experiences, knowledge, and best practices is important to finding the right balance on all matters pertaining to HSE.

Saudi Aramco served as a co-sponsor of the four day event, which brought together more than 5,000 professionals representing over 150 companies from more than 30 countries.

Optimization Study of Temperature Log for Fracture Height Evaluation and Field Application of Practical Examples after Pad Calibration

Adrian Buenrostro, Mohammed Al-Abdrabalnabi, Amro E. Mukhles, and Saad M. Al-Driwees

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Fracturing is a complex technique utilized to stimulate hydro-carbon reservoirs to enhance their production. The theory, tools, and techniques utilized for fracturing are complex and very specific. With the demanding increase of hydrocarbon production, proppant and acid fracturing are widely implemented, and in some cases, is the unique solution to having commercial production, i.e., unconventional gas reservoirs.

The optimization of the fracturing process is important since this activity is complex, expensive, and in most of the cases, required for commercial production. Several parts of the pro-cess are known based on previous experiences. In other cases, complex studies still need to be done to better understand each case, to enable a more accurate propped fracturing execution. To be confident in the case of design, execution and evaluation of a proppant fracturing job, fracture geometry determination is very important, as this drives the adequate evaluation and job execution while also allowing for job optimization. One of the basic and most important values to estimate the fracture geometry is the fracture height; once this parameter is determined, fracture width and fracture length can be determined with less uncertainty, based on other parameters from log data, job execution, etc. The fracture geometry can be estimated more confidently if the fracture height value is set.

This article studied and compared multiple scenarios of sandstone reservoirs. The study was made for fracturing jobs focused on gas and hydrocarbon production. Tight conditions and unconsolidated sandstones were dominant scenarios of the fracture jobs. The parameters utilized for this study were focused on some log signatures, which were observed to drive the criteria of the fracture height growth. Based on those parameters, the project attempts to simplify the process of fracture height determination. The exercise was made for a group of wells in different areas of the reservoirs where some parameters prevail, and we are confident in the gathered information. The signatures observed proved helpful to confidently predict the expected fracture height. In the exercise of this project, all the examples were made with cases where the temperature log was made after reading the fracture data of the obtained frac-ture height by the temperature log criteria 1.

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This project was made in wells that produced outstanding gas rates from its reservoirs over a period of decades. Stimulation by proppant fracturing at the sandstone reservoirs become a regular requirement to find commercial production after new areas were attempted for production. The process of proppant fracturing started with multiple uncertainties from the reservoir point of view, and also for the logistic part at the job execution as fracturing was not previously used. The regular fracturing startup process involves reservoir log-ging evaluation, injection test, completion hardware setup, soft-ware simulations, and lab tests for compatibility, and forecast studies for production results, among other challenges. Specific studies and tests were conducted in preparation to the first field applications. During the startup process, it was observed that a wide range of parameters need to be clarified prior to deploying the stimulation in the field.

Figure 1 shows the parameters used for a fracture geometry in a generic way, simplified to have the total length, height, and width, represent a volume. In real cases, a fracture is not a geo-metrically perfect square or rectangle; but to simplify equations and analysis, computational models assume simplified shapes of fracture geometry for processing calculations. In general, for a fracture geometry determination for the three main dimensions; the length (L in Fig. 1, or “d” in Table 1), width (W), and height (H), are based on:

- The amount of energy placed (pressure while pumping and pumping rate).
- The amount of mass used (fluids + proppant).
- The amount of energy dissipated (fluid efficiency and pressure variations). Fluid efficiency is related to the fluid amount pumped, the amount lost in fracture geometry to the formation due to leak-off, and the fluid effectively creating a fracture geometry.

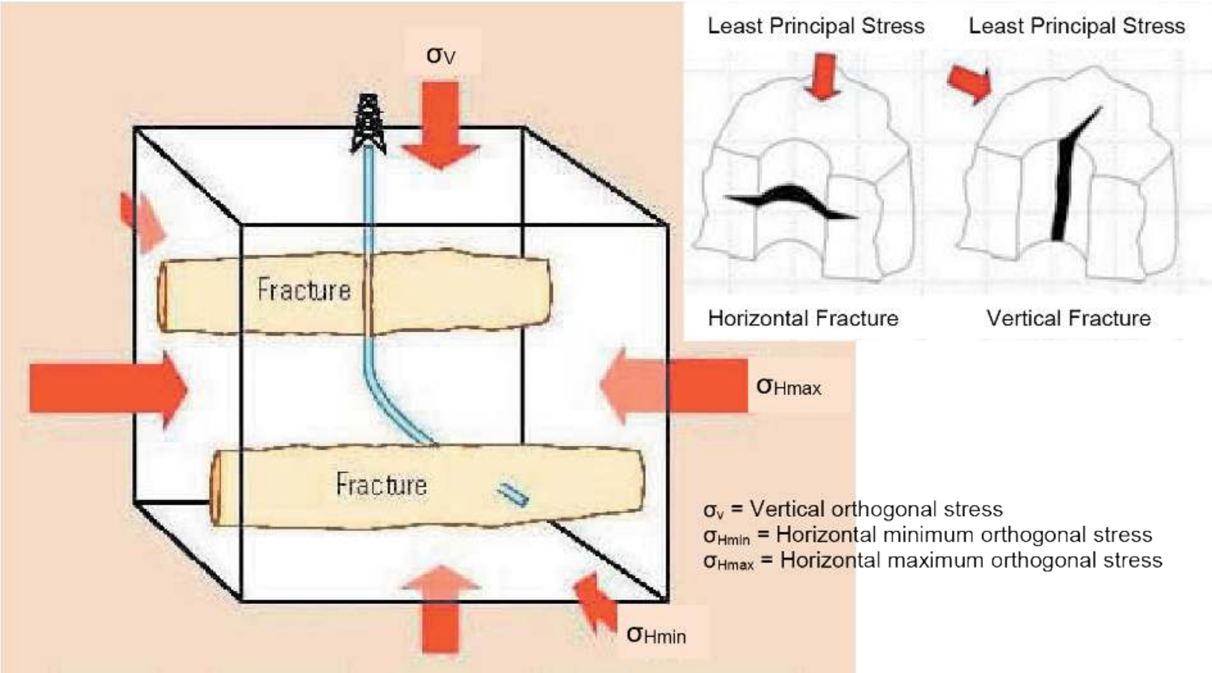

Fig. 2. Fracture geometry development from the wellbore related to the formation stress orientation, which can be either vertical or horizontal.

Note that in Fig. 1, the length is only for one fracture wing, as the fracture is assumed to develop symmetrically — the same geometry on both sides from the wellbore to the formation. The fracture volume and geometry is standard, referring only to one wing or side of the fracture.Width, according to fracture geometry calculation, is based in different models of the fracture, and is directly related to$_2$: EE′=E1−ν$_2$ (1)where H = frac height, L = frac length, R = radial growth, μ = viscosity of fluid, Q = pumping rate, E' = plain strain modulus, E = Young's modulus, and ν = Poison's ratio.The fracture width can be calculated in general by:ww ∝ [QQQQ LLEE′]$_{1/4}$(2)Following Fig. 1 and Table 1, and Eqns. 1 and 2, it is observed that the width is driven by Q, μ, L, and formation mechanical parameters. This concept is a simplified way to calculate the fracture "d"W (width)Perkins and KernH(μQL/E')$_{1/4}$RadialL(μQR/E')$_{1/4}$Gertsma deKlerkR (radius)(μQL2/E'H)$_{1/4}$

	"d"	W (width)
Perkins and Kern	H	$(\mu QL/E')^{1/4}$
Radial	L	$(\mu QR/E')^{1/4}$
Gertsma deKler	R (radius)	$(\mu QL2/E'H)^{1/4}$

Table 1. Fracture Geometry Model's to calculate the main dimensions

in correlation to a general fracture model, whereas other parameters, i.e., pumping pressure, net developed pressure, and leakoff, among others, may affect the fracture's width. As previously mentioned, the three main dimensions, length, width, and height, are simplified for the analysis made to calculate them to obtain the fracture geometry. Since there are three main variables for one model, the definition of any of those three values simplifies the calculation of the other two dimensions. Therefore, when there is a chance to measure any of those parameters, the fracture geometry can be determined more confidently. It is possible for the fracture length and width to drastically vary, depending on the fracture height determination; whereas once one value is determined, fracture optimization is feasible. Additional technologies can be used to measure the width and fracture length. Those technologies are usually complex and present multiple concerns; as some can have limitations and logistic issues due to their particular requirements, which means that the implementation of them is then not always pos-sible. Fracture height in another way is easy to measure when the fracture plane is collinear to the wellbore, which commonly is the case of vertical wells, where most of the geomechanical conditions of the reservoirs place the wellbore collinear with the fracture plane, Fig. 2. The natural arrangement of the main stress orientations in the reservoirs make a vertical wellbore suitable for developing a vertical fracture plan, thereby making the fracture height collinear with the wellbore$_3$. The characteristic of a vertical well, being collinear with the minimum in situ stress of the rock, allows the fracture created to develop its height attached to the wellbore from the top to bottom height of the fracture.

An important temperature contrast is generated from the fluid injected in the formation at the depth where the fracture is placed at perforations made on the wellbore. The reservoir is usually dozens of degrees hotter than the injected fluids. The change in temperature is made by the fluids pumped into the formation, which starts cooling down the well from the surface, the wellbore completion, and finally reaching the reservoir. Equation 3 describes the parameters used to analyze the temperature change according to thermodynamics by three ways: conduction, convection, and radiation, Fig. 3. Conduction is the most important for the case of heat exchange in the formation between the rock, completion tubulars, and fluid injected during a fracture job.QQ/tt∝kkkk(TT_{HHHHHH}− $TT_{CCHHCCCC}$); (3) where Q = energy (W), t = time(s), k = heat transfer coefficient [W/((m2)(°C))], A = heat transfer area (m2), THot = temperature of the hot mass (°C), and TCold = temperature of the cold mass (°C).

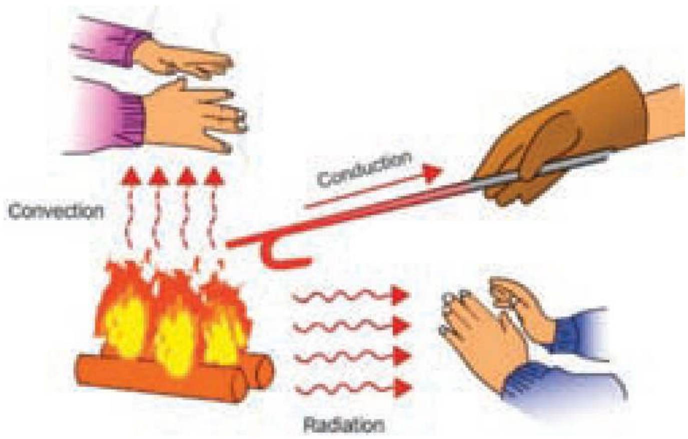

Fig. 3. General heat transfer paths by conduction, convection, and radiation.

FIELD CASE APPLICATION

For the case of a fracture geometry investigation, fluid is pumped from the surface (bull heading) through the wellbore completion to the formation. Fluid is pumped at surface tem-perature, around 20 °C to 25 °C. The formation rock where the fracture is being made is several degrees hotter, and dissi-pation of the temperature will be driven by reservoir conditions depth, reservoir fluids, and rock type, among others. A reservoir at around 4,000 m deep will have approximate tempera-tures of 150 °Cto 180 °C. The difference from the reservoir temperature with the injected fluid generates an important cool-down at the area of injection where the fracture is generated. This temperature contrast dissipates with time, and depends on formation properties to accelerate or restrict the temperature to cool down or heat up. Usually, after several hours 6 to 12 hours a temperature contrast can be measured from the wellbore to the formation. During the process of a proppant fracture job for the study, injected cold fracturing fluid is usually no less than 50 m3 of base water fluid, injected into the rock, which is a porous media filled with gas, oil and/or water. The process is made in as high a rate as possible to fracture the formation under con-trolled parameters. The pumping rate used is from 3 m3/min to 7 m3/min, therefore, the fluid is injected in 10 to 15 minutes.

Quick injection allows for a higher temperature contrast at the core of the injection point, which decreases with distance from that point, until a distance where original reservoir conditions (temperature) are not disturbed because no fluid reaches that point. Figure 4 shows the reservoir depth, when the fracture plane is collinear with the wellbore, it can be interpreted based on the temperature profile contrast observed on the readings of a log made with high-resolution readings, i.e., a high-resolution temperature (HRT) log. Figure 4 represents a logging job, where tools are placed into the wellbore by running in hole (RIH), and recording the temperature changes.

As observed in the left log plotted lines, there are two continuous lines, thick and thin each one close to a dashed line the dashed line in each case is straight, and used as a reference to the perfect incremental profile of the temperature for this log case. The continuous lines are the real temperature readings by the log in the well. They are not straight different layers on the reservoir commonly have small variations in temperature. Most of the time, temperature logs are repeated over periods of time; for particular objectives where changes on the temperature profile is expected to provide information to make decisions on well conditions. To have a case by case reference about temperature profiles, the performance for each well was studied at initial temperature conditions. For this, an initial log was made when the well was undisturbed, at the startup of the well life; the initial log was then the base reference for comparison, so further temperature changes could be identified.

Due to the disturbance of wellbore fluids, and the thermal hysteresis of the temperature log for the bottom-hole assembly, temperature readings differ if made RIH or pulling out of hole.For a proppant fracture job, the temperature

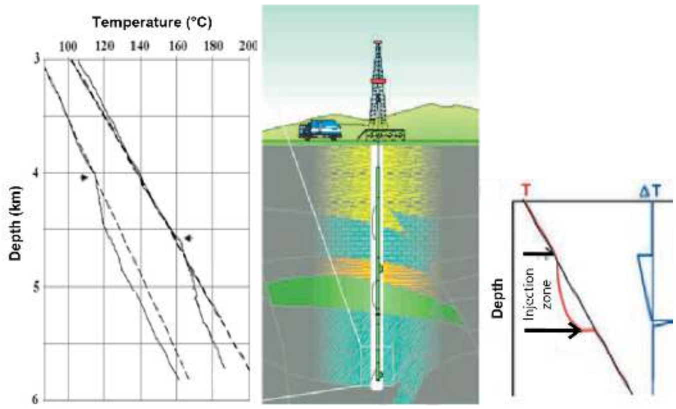

Fig. 4. Logging a well for temperature log.

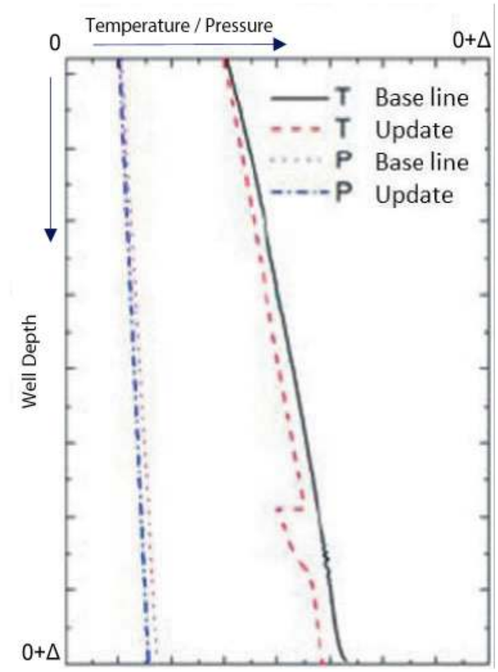

Fig. 5. Example of temperature drop at the injection zone; the temperature falls from expected undisturbed profile due to fluid recently injected.

log when the well was undisturbed, is compared with the temperature log made after injection of the fluids, either for fracture evaluation or after the main fracture job, to document the final fracture height. This information was obtained by selecting the points where the temperature profile differs from the normal temperature base line. The temperature increases as the depth increases, resulting in a deviation of temperature profile, where a cool-down is observed close to the injection point at perforations which suggests that the pumped fluid has invaded the reservoir at the perforation zone. The readings must be done above and below the disturbed zone of injection, where the temperature deviates from a normal trend above and below the perforations, suggesting fluid invasion related to height.

Above the perforations, the temperature has a similar slope to the original temperature log, but below the perforations where the fluid was not disturbed, only the area of fluid invasion shows a cool-down. Deeper points show undisturbed temperatures from the initial conditions. To verify the validation on readings as well as dissipation of a cool-downat the injection section, subsequent logs in specific time intervalsare made. For this study, the standard time is 2 hours between readings. The first reading should be done as soon as possible afterinjection. Due to logistics and the surface operation sequence of activities, usually the first temperature log is made from 4 to 6 hours after injection, Fig. 6.

Based on the temperature log, fracture height is determined and the temperature drop behavior can suggest whether or not the fracture is well contained. Some cases show the fracture height distribution to be higher above or below the perforations, or an extremely big fracture height, which usually shows a smaller temperature drop as the fluid mass is distributed overa longer area. The amount of hot rock from the reservoir in ratio to the liters of fluid injected is always major. In smaller zones where all injections are contained, more water is available to cool down the formation rock per the height of the exposed rock; in those cases, the cool down is more evident. When water is not well contained in the fracture, it grows or develops a larger height; as in the case where each volume of liquid is exposed to more area of contact with the formation rock, which is very hot compared to the injected fluid.

Therefore, the energy of the fluid, which can influence a change in the temperature of the rock, is less than when it is exposed to a smaller rock section. This criteria is utilized for the multiple (usually a total of three) temperature logs made to determine if with time, therock tends to dissipate the fluid in the fracture created under a non-homogeneous profile all lines on the temperature log becoming parallel to each other at any single depth. This case can be interpreted as the presence of a “dominant” fracture zone, which shall be considered for the fracture design and execution as the risk of fracture propagation could not be constant during the execution, increasing the chances of issues to complete the job as desired. Note that trend variations among subsequent logs could indicate differential closure

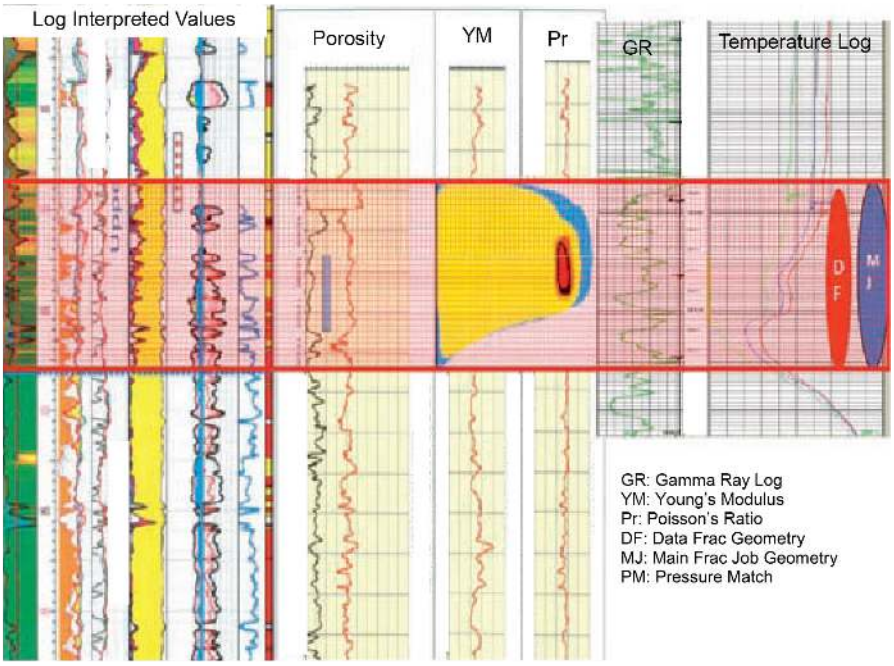

Fig. 6. Example of a temperature log after injection with time intervals for subsequent logs; base line temperature log as a reference.

conditions at various reservoir layers related to the fracture. The interpretation of such cases is important, but is a particular topic to be covered by specific study, which is not the case for this article.

After several years and dozens of temperature logs made,the temperature logs showed mostly average behaviors on fracture geometry "height" description. So far, no more than 85m (~275 ft) of fracture height has being identified, while also never finding a developed fracture of less than 21 m (70 ft) in height. The average fracture height in general is found to be around 33 m (120 ft), and it was observed that certain parameters on the log are usually related to the fracture height limits, suggesting those values are affecting or directly impacting the fracture height development.

Based on those observations, a tracking data study over the recorded logs was made; it revealed a trend on the well logs compared to fracture geometry. The designed and post-job pressure matched fracture jobs were used and correlated to observe the trend of the fracture height, which was related to the most influential values on the logs. These values can be utilized to confidently predict the fracture height without needing a temperature log. Among more than 20 values observed on the logs, e.g.,gamma ray, porosity, Poison's ratio, Young's modulus, silts, saturations, rock quality by reservoir point of view, etc., the study was made to compare which parameters had a larger influence on the fracture height limitation.

Based on the observations made, the logs compared all inputs with fracture geometry predicted by design, fracture geometry adjusted by pressure match of the job execution (with real measured values), and with well log interpretation (additional criteria over the basic logs, gamma ray, sonic traveltime, etc.). The jobs were visu-ally arranged, with the observation and correlation of all data in images used to match the depth of the perforations, and to compare the log values with the fracture height obtained by design, and then compared with the real temperature log avail-able after injection, Fig. 7.

The study was made over more than 50 wells, which at that moment had available all the information required. Several more wells were also studied, but some of the information was not available or was incomplete. To have the most complete examples of better discretization on the parameters for this study, only the cases with all information available were used. Table 2 shows the details of the first base line study made, which corresponds to 40% of the wells analyzed as those cases for which observations were made with complete confidence. Note that some data was considered important for some experts, but was not mapped on the study, and is not shown in Table 2.

This decision was made as those parameters were constant for all cases, and did not influence the fracture height interpretation, e.g., perforation gun type4, base line frac fluid, and injection test fluid type, among others. The normal sequence of every job was:

Well Case	Field	Area	Formation	Fracture Height (ft)	Perforation (ft)	Stress	Porosity	Gamma Ray (GR)	Comments
19	B	C-N	W	90	20	Dominant	Dominant	No Influence	Stress and porosity determine fracture height
20	B	S-E	X	110	30	Dominant	Dominant	Certain Influence	High contrast on stress, peaks, thin layers
21	B	C-E	X	83	40	Dominant	No Influence	Dominant	Temperature log may be off, case under concern
22	B	S-E	X	80	20	Certain Influence	Dominant	Certain Influence	Porosity dominates the fracture
27	B	C-E	X	275	25	Dominant	Dominant	Certain Influence	Indiscretional height growth
28	B	C	X	100	40	Dominant	Dominant	Certain Influence	Stress and porosity determine fracture height
30	B	C-E	X	200	20	Certain Influence	Dominant	Certain Influence	Porosity dominates the fracture
35	B	C	Z	120	30	Dominant	Dominant	Dominant	Stress and porosity determine fracture height
36	B	C-E	Z	180	40	Low	Dominant		Pr influence
37	B	C-E	V	150	95	Low	Low	Dominant	GR shows more influence followed by YM
38	B	C-E	V	70	62	Certain Influence	Certain Influence	Dominant	No HRT available
39	B	N-E	V	110	30	Dominant	Certain Influence	No Influence	Stress dominates the fracture
40	B	C-E	V	180	30	Dominant	Certain Influence	Dominant	Pr influence

Table 2. First base line study to set the criteria of fracture height prediction based on logs

1. Do a small injection test with potassium chloride-based brine; in all cases the same fluid is used.
2. Perform a step rate test and/or step down test.
3. Calibrate the injection with cross-linked fluid as per the planned one for the main job.
4. Run a temperature log (HRT), and study the data from step 3.
5. Execute the main job proppant fracture execution (based on step 3).
6. Perform a pressure match of the job, to be adjusted as per the HRT.

This study allowed us to upgrade the operation by swapping the sequence as per the following steps:

1. Interpretation of the logs.
2. Comparison of correlated wells to match the criteria on possible fracture height by dominant parameters.
3. Compare with fracture simulation by fracture design computational software.
4. Execution of the job.
5. Pressure match to evaluate differences on geometry results by software analysis.

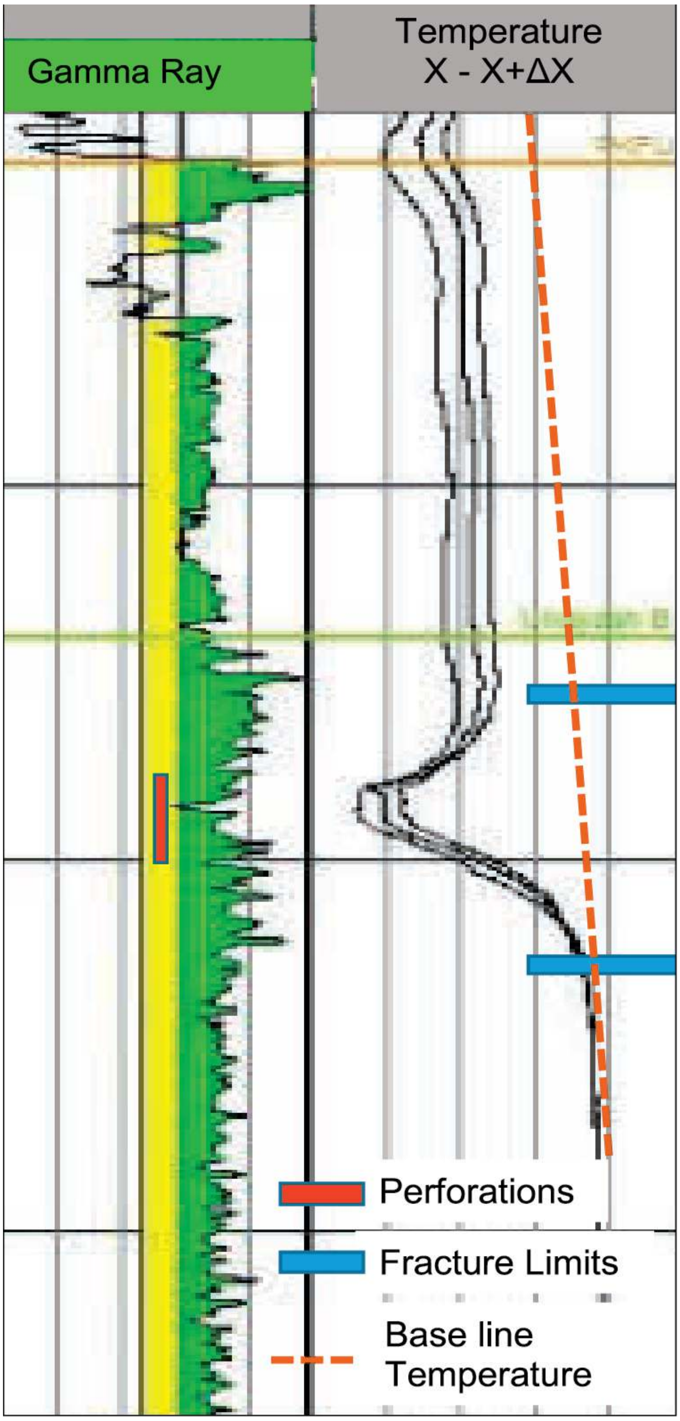

Fig. 7. Example of the exercise made on every case of the study to analyze logs vs. fracture geometry suggested by computational analysis. Fracture geometry generated by computer is the yellow oval shape over the Young's modulus (YM) and Poisson's ratio (Pr) logs. The red dash section represents the fracture height related to all other parameters related by depth.

The main advantage of the upgraded steps is that no temperature log is required, DataFRAC is avoided, thereby saving no less than 24 hours while optimizing the fracture design based on previous experience.

OBSERVATIONS AND CONCLUSIONS

The study's conclusion was reviewed and utilized to set the forecasted or predicted fracture height in wells where the HRT was still required, to prove with confidence that the criteria found was reliable. So far, over 25 cases were observed to match the criteria of the fracture height prediction with less than a 15% error, which for the purpose of these main fracture job designs, the adjustments for time savings and cost optimization, and the impact on operations could be obtained.

The study set this criteria as reliable for application in field operations to confidently avoid the usage of a temperature log. The study continues to be fine-tuned as areas outside of the actual studied wells are still under development. It was found to have similar trends on criteria for those areas. Table 2 prevailed to be valid in terms of holding the most important criteria to confidently predict the fracture height based on log interpretation. The trends for this criteria narrows more when the type of reservoir and average job profile is similar to the ones pumped in the studied cases. Two job types, in terms of volume and rate, were used. When discretization is made at the same job approach, the fracture height can be predicted with minimal error.

OUTLOOK

1. The project proved to be valid based on previous data and a new test was made with the HRT to validate the prediction. More wells are being added to the study, and the addition of new cases is important when the well is drilled in areas where correlations are expected to be similar to studied scenarios. This will help to finetune the criteria to predict the fracture height with more confidence.

2. The study could be extended to other areas of application, i.e., prediction of fracture volume, fracture total geometry (length in particular, width as well), perforation enhancements5 by fracture observations, the fluid success ratio on fracture execution, and conditions to evaluate potential screen outs, etc.

ACKNOWLEDGMENTS

The authors would like to thank the management of Saudi Aramco for their support and permission to publish this article. The authors would also like to thank Nahr Abulhamayel and Yousef Noaman, for this project execution and the continuation of it.

The article was presented at the SPE Kingdom of Saudi Ara-bia Annual Technical Symposium and Exhibition, Dammam, Saudi Arabia, April 23-26, 2018.

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The Future of Nonmetallic Composite Materials in Upstream Applications

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Corrosion in oil and gas operations is generally caused by water, carbon dioxide (CO2) and hydrogen sulfide (H2S), and can be aggravated in downhole applications where high temperatures, combined with H2S, introduce other challenges related to corrosion and iron sulfide scale formation. The repair costs from corrosion attacks are very high and associated failures affect on plant production rates and process integrity. To overcome this existing problem in upstream, nonmetallic composite materials were introduced for drilling, tubular, and completions in high risk, corrosive environments the goal being to increase the well's life cycle and minimize the effect of corrosion, scale, and friction in carbon steel tubulars. The new proposed materials are lightweight, have high strength, and have superior fatigue resistance, in addition to an outstanding corrosion resistance, which is able to surpass many metallic materials.

The economic analysis shows that utilization of nonmetallic tubulars and linings will yield substantial life cycle cost savings per well, mainly due to the elimination of workover operations. Subsequently, with these advantages, composite materials pose several challenges such as single source provision, high initial cost of raw materials, the manufacturing process, and the limitation of nonmetallic standards. As a result, the polymer and composite solutions for upstream oil and gas use are still very limited, even in targeting low risk applications such as low temperature and pressure scenarios. Therefore, research and development (R&D) efforts are ongoing to increase the operation envelope and introduce cost-effective raw materials for high-pressure, high temperature (HPHT) subsurface applications.This article highlights practical examples of nonmetallic materials selection and qualification for upstream water injector/producer and hydrocarbon wells. Several future nonmetallic applications in upstream will be summarized. Challenges and R&D forward strategies are presented to expand the operation envelope of current materials and increase nonmetallic deployment to more complex wells, i.e., extended reach drilling.

Introduction

Carbon steel is the preferred material of choice for downhole applications. Carbon steel has distinct advantages over other materials in terms of material cost, temperature and pressure ratings, and field construction support services. One downside of a carbon steel flow line is a limited "lifetime" due to corrosion, but also includes repair cost, maintenance costs, and corrosion monitoring. The corrosion rate is also gradually increasing, which is attributed to the presence of hydrogen sulfide (H2S), carbon dioxide (CO2), and high cuts of highly saline waters. Corrosive fluids are generally handled by chemically inhibited carbon steel and corrosion resistant alloys (CRAs). The CRAs significantly increase the project cost and complexity. Currently, the oil and gas industry is considering different techniques to combat corrosion and one of these techniques is the utilization of nonmetallic products.

The nonmetallic composite materials help to reduce capital and operational expenses without ignoring the safety, reliability, and long-term performance. Nonmetallic composite materials have been widely used in onshore and offshore applications, including line pipe systems, flow lines, and topside applications (grates, ladders, and tanks). For instance, rigid reinforced thermoset-ting resin (RTR) pipes and reinforced thermoplastic pipes (RTP) were utilized for a number of years in a variety of onshore and offshore hydrocarbon service applications, and have proven to be successful to control corrosion and enhance the system reliability, Fig. 11.

The successful experience of the deployment of nonmetallic materials downstream in onshore and offshore applications has paved the way to increase the deployment in downhole applications.

The main business drivers to increase the utilization of nonmetallic materials in upstream oil and gas applications, include1:


Fig. 1 Onshore field deployment of RTR (left), and RTP (right)1.

- Reduce the cost of the well by using lower horsepower capacity drilling rigs.
- Improve well integrity through the utilization of noncorroding materials, and accordingly, increase the well's life cycle.
- Reduce operational time and risk through the han-dling of lighter tubulars, and minimizing the potential lockup/buckling in downhole due to less friction.
- Promoting the conversion of oil to petrochemicals (boosting the feedstock for nonmetallic products would increase demand for oil).
- The fiber optic sensing can be easily embedded in the composite system and this will help to optimize the upstream operation by collecting downhole data.

In fact, the deployment of nonmetallic materials in upstream is strategic and aligns with industry trends. Subsequently, in upstream applications, specifically downhole environments, the conditions and standards applicable to the common flow line no longer applies. The material is subjected to a more complex set of dynamic stress conditions under variable multiphase fluids internal and external and temperatures. Several forces such as internal pressure (burst), external pressure (collapse), tension, and axial compression play a significant role in the nonmetallic downhole tubular performance.

These materials offer lightweight, high strength, superior fatigue resistance, and outstanding corrosion resistance that is able to surpass many metallic materials. In many cases of downhole deep well operations, the service tools are required to perform at a temperature of 150 °C to 232 °C, and under a pressure ranging from 5,000 psi to 15,000 psi — most of the time in a wet environment2. As a result, the applications of nonmetallic composite downhole are still very limited, which requires an intensive research effort with service companies and academic.Currently, the industry has explored the opportunity to deploy nonmetallic materials in upstream with low hanging fruit applications, and at the same time, work-ing on research and development (R&D) supports the expanding operating envelope targeting high-pressure, high temperature (HPHT) applications. This application is seen by the industry as significant and strategic for upstream operations.

Composite Materials and Design Selections

Composite materials are made from combining two or more materials, which provides the new material with unique properties, over and above the original materials. Nonmetallic composite materials are divided in two groups as fiber reinforced plastics and fiber reinforced resins. The matrix materials are classified into three categories: (1) thermoplastic, (2) thermosetting, and (3) elastomeric. A diverse array of reinforcements are used, which includes glass, carbon, and aramid. The fiber reinforcement has different grades, and it can be used as a tape or in the form of braided fibers.

The role of the fiber is to carry the overall load and the role of the matrix is to transfer the stress within the fiber, and protect the system from mechanical damage.The proper material selection of fiber and matrix for downhole completion equipment essential in considering functional requirements, temperature, pressure, chemical and abrasion resistance is key to a safe, reliable, fit for purpose and cost-effective operation over the design life of the well. In piping, the combination of these raw materials is used to make final composite products such as the RTR pipe and RTP, and the most recent technology use is the thermoplastic composite pipe (TCP). Each composite has a different design and manufacturing process. The RTP structure is composed of three layers not fully bonded: (1) an inner layer that acts as a bladder and contains the process stream, (2) an inter-mediate layer that reinforces the pipe, and (3) an outer sheath that protects the pipe from wear, impact, and weathering effect. Figure 2 shows the configuration of the RTP.

Fig. 2 The configuration of the RTP3

Consequently, the TCP is made from three layers: (1) a liner, (2) a composite, and (3) a protective layer, forming a fully bonded solid wall pipe4. The TCP structure is made from either tape carbon or aramid fibers, which are designed for high-pressure applications. The TCP concept is increasingly gaining the attention of the oil and gas industry4. The RTR or fiberglass pipe is manufactured by a helical filament winding process. The fiber is embedded in an epoxy matrix and laid in an axial and hoop direction. Depending on the applications and downhole conditions, fibers and polymer materials are defined, such as glass or carbon/aramid fibers and high performance engineering thermoplastic polymers such as polyphenylene sulfide (PPS), polyetheretherketone (PEEK), andpolyvinylidene fluoride (PVDF) as a promising material for downhole applications. This is because of the superior properties of the semi-crystalline resin that has good chemical resistance at high operating temperatures[2].

Table 1 shows key mechanical and physical properties for assessing the suitability of polymers and fibers for downhole applications. The selection of materials for downhole use, such as tubular, completion and drilling equipment, shall be evaluated based on international standards in line with the International Organization for Standardization and the National Association of Corrosion Engineers. This helps in selecting the proper nonmetallic materials for the downhole environment. In general, there are several key properties that need to be evaluated during material selection.

These properties include:

- Compatibility with the service environment.
- Withstanding downhole stress (burst and collapse pressure).
- Thermal expansion.
- Tensile, strength, elongation at break, modulus of elasticity at minimum and maximum temperatures.
- Swelling and shrinking (mass and/or volume) by gas and by liquid absorption.
- Gas and liquid permeation.
- Resistance to gas decompression.
- Creep resistance at HPHT.
- Resistance to thermal cycling and dynamic movement.
- Chemical resistance to stimulation treatment.
- Erosion and abrasion resistance.

The numerical simulation is a very essential tool, which helps in selecting the proper materials, fiber orientations, and the thickness of composites, which suits certain applications. The simulation work is a key element to optimize the selections and decide the most economical solution based on the operating conditions. Table 2 summarizes the proper fiber and matrix materials selection based on the different operating conditions and well service. A multilayer fiber needs to be considered in case of high pressure in downhole applications.

Table 1 *Key mechanical and physical properties for assessing the suitability of polymers and fibers for downhole applications.*

Composite Materials	Name	Strength (MPa)	Young's Modulus (GPa)	Tg (⁰C)	Tm (⁰C)	Continuous use Temp (⁰C)
Fibers	Glass	1,800	70	-	-	-
	Carbon HS	3,200	230 - 350	-	-	-
	Carbon HM	2,500	> 400	-	-	-
	Aramid	3,000	65 - 130	-	-	-
Polymers	PEEK	80	-	143	334	190 - 210
	PPS	70 - 135	-	85 - 250	285	170
	PVDF	40 - 60	-	- 60	170	150

Table 2 *Proper selection of fiber and matrix composite materials for different operating conditions and well service.*

Well Service	Downhole Conditions	Reinforcement	Matrix
Water	Low to Moderate Pressure and Temperature	Glass	Epoxy
Oil	Moderate to High Pressure and Temperature	Carbon, Aramid	Epoxy, PVDF,PPS
Gas	HPHT	Carbon, Aramid	PVDF,PPS, PEEK

Future Nonmetallic Applications

Various composite applications, including drilling and completion, have been evaluated by actual field deployment. These applications are still limited because of the materials' cost, and the limiting number of available industrial guidelines and standards supporting downhole applications. The existing applications of nonmetallic use downhole, such as a casing centralizer, drillpipe protector, and glass reinforced epoxy (GRE) liner, have been guided and deployed by engineering experience on a case-by-case basis.

Figure 3 explains several downhole applications that have been replaced or are expected to be replaced over the next few years. There are many future deployment opportunities to utilize nonmetallic composites as a cost-effective solution for upstream. Some of these technologies are at low technology readiness levels, which require more R&D efforts. Other materials need thorough technical evaluations to meet field proponent acceptance and make them feasible for downhole applications. Currently, there is a well-developed process in the industry to align nonmetallic deployment and development among different proponents, technical organizations, and R&D entities, to expand the operating envelope and resolve potential challenges based on field trials. The following are several promising upstream applications where the composite can be utilized and tested over the next few years, Fig. 4.

Nonmetallic Tubular

The full nonmetallic composite tubular (tubing/casing) and velocity string provide an alternative solution to the conventional carbon steel. It provides internal and external corrosion resistance when the tubular is exposed to a severe corrosive environment. Another advantage of composite is high ductility, and lighter weight — around six times — compared to steel tubular5. The use of the GRE tubular has increased significantly during the last few years in shallow water applications. Currently available composites on the market are able to operate at a downhole temperature not exceeding 100 °C, however, research is underway to use composite materials for working temperatures from 150 °C to 170 °C in geothermal wells deeper than 3,500 m5. The industry has started to realize the high impact of expanding the operating envelope of current composite tubulars. In the future, the development of composite materials capable of operating in high borehole temperatures and/or pressure are being investigated to cover seawater injection, disposal, and supply, along with hydrocarbon wells. As a result, the

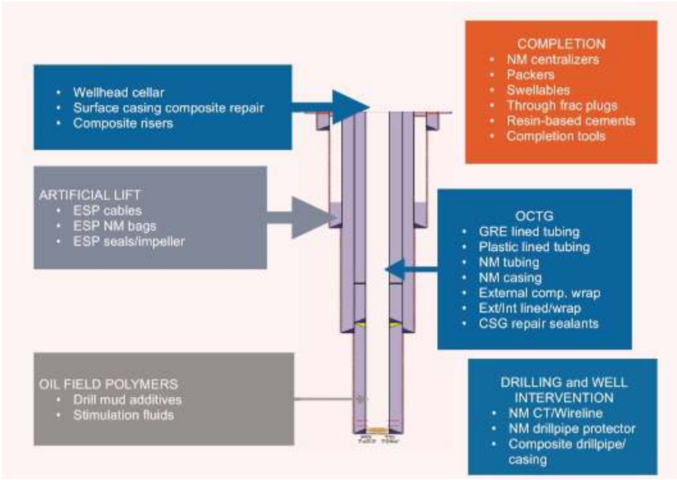


Fig. 3 *Nonmetallic development roadmap for the current and future downhole applications.*

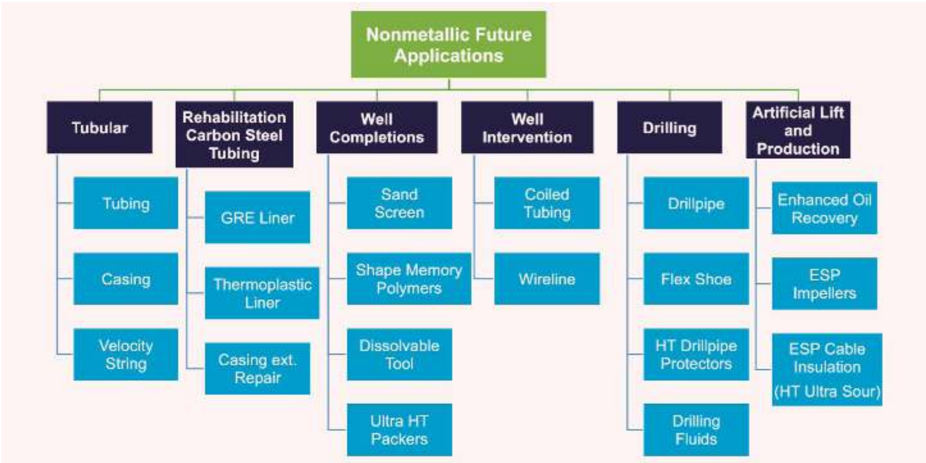


Fig. 4 *A summary of the future potential applications of nonmetallic composites in downhole use.*

complexity vs. time matrix is being developed to support the development plan promoting the composite utilization in upstream oil and gas operations, Fig. 5.The selection of proper composite materials — fiber and matrix — and the understanding of downhole stress (burst, collapse, and tensile), are important factors to select the right composite tubular design that suits specific downhole conditions. In the case of tubing, composite designs include flexible (RTP and TCP) and rigid (RTR), which are all currently under technical consideration. In the case of casing, designs considering a rigid composite (RTR), are under technical consideration as well. Based on the available composite design products in the market, Table 3 explains the optimal target requirements of pressure and temperature envelopes that need some extra effort from the industry to develop cost-effective composite solutions meeting the following downhole conditions. Currently, the main industry focus is in water applications, including supply, injection, and disposal wells, since they present less associated risk and are cost-effective solutions compared to carbon steel.

For instance, the full nonmetallic composite tubular composed of GRE, Fig. 6, has been tried worldwide in shallow water supply and observation wells6. The use of fiberglass casing in an observation well is becoming an area of interest, because it allows for the use of some deep induction open hole logging tools for measuring the changes in formation properties behind the casing7. Enhancing the performance of current GRE casings and tubings above a rated pressure of 5,000 psi is feasible, by using high glass transition temperature point epoxies coupled with seamless manufacturing techniques, such as the rotational casting manufacturing process, strives to minimize composite body porosity and enhance the mechanical integrity at high temperatures. In fact, some manufacturers have developed prototypes that have been initially pilot tested8. On the other hand, one of the most challenging aspects is related to the leakage at the tube joints. Therefore, parallel research and validation should be done at the same time in this area. The development of nonmetallic composite tubulars for oil and gas operations are quite challenging, due to the high initial costs of raw materials, special manufacturing processes, and the complexity of the downhole operating conditions. Therefore, several technical and economic factors need to be evaluated as part of the feasibility studies.

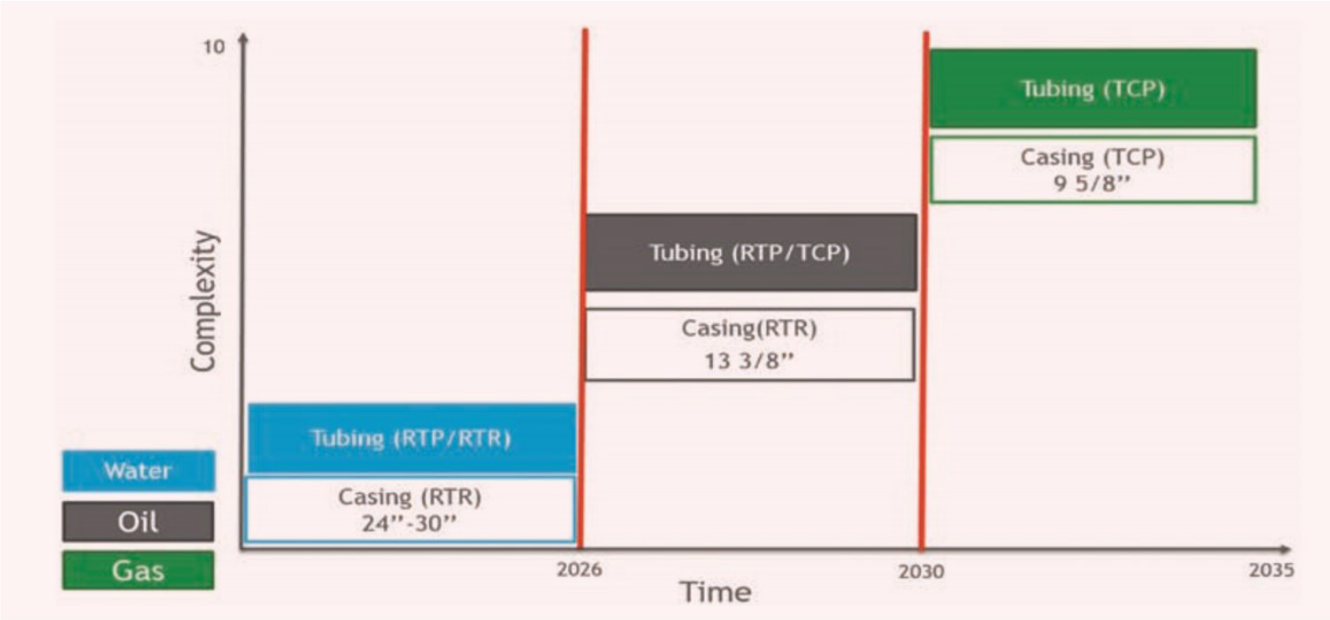


Fig. 5 *Matrix development plan of composite tubulars.*

Application	Casing			Tubing		
	Most Wells			Water	Oil	Gas
Outside Diameter	30"	13 $^{3}/_{8}$"	9 $^{5}/_{8}$"	4 $^{1}/_{2}$"	4 $^{1}/_{2}$"	4 $^{1}/_{2}$"
Burst pressure (psi)	2,000	4,000 to 7,000	12,000	4,000 to 5,000	7,000 to 10,000	10,000 to 15,000
Collapse pressure (psi)	1,500	2,500 to 6,500	11,000	4,000 to 5,000	7,000 to 10, 000	10,000 to 15,000
Temperature (°F)	150° F	260° F	320 °F	200 °F	260 °F	260 °F

Table 3 *Proposed R&D target requirement of nonmetallic composite tubular development.*

As a result, the right decisions need to be made based on the following important factors:

- The life cycle of metallic pipes — frequent failure.
- Upgrading metallic materials (CRA) vs. composite cost.
- Workover cost.
- Production loss cost.

Location, either offshore or onshore. Besides the tubular, the velocity string is a low hanging fruit application to utilize the RTP or TCP composite design replacing a conventional steel string.

Installing a velocity string reduces the flow area and increases the flow velocity to enable liquids to be carried from the wellbore. Velocity strings are commonly run using coiled tubing (CT) as production means.

Figure 7 shows a schematic of this technique[9]. The industry has realized the high impact of the composite velocity string, due to its ability to run riglessly, the ease of installation and the ability to eliminate the premature corrosion with metallic strings. The main target is to deploy the com-posite velocity string in the shallower vertical/deviated unconventional gas, oil, and water wells, and then the composite operating envelope will be improved, targeting extended reach applications. Increasing the reliability of the nonmetallic composite tubular covering many applications in downhole is a significant milestone. To achieve this target, several associated challenges were identified that need to be addressed as part of the development plan. Those challenges are related to well completion and intervention operation, such as the packer setting, perforation, cementing, completion installation, and joint connection.

Thermoplastic Lined Carbon Steel Tubing

The internal lining technology with conventional GRE material has been widely used in the industry as a method for corrosion protection of downhole carbon steel tubing, Fig. 8. Thermoplastic liners or poly liners are another technology for downhole tubing products, which have presented a significant impact for reducing

Fig. 6 *Full RTR/GRE tubing design for a water supply well.*

corrosion failures, with abrasive resistance in injection, disposal, and hydrocarbon wells. The thermoplastic liner is a thin layer of plastic, which is mechanically inserted inside new or used carbon steel tubing, and may offer a competitive advantage over CRAs in term of cost and life cycle. The cost savings were realized with fewer workovers and increased tubing life10. There are four commercially available thermoplastic liner materials, and each has a limited temperature envelope of operating in wells up to 260 °C. For instance, the most commonly used thermoplastic liners in oil and gas production services are largely extruded from polyolefin for installation in environments up to 99 °C; yet, for more demanding environments, engineering thermoplastics such as PPS are available to handle temperatures as high as 175 °C. In the most extreme production environments with temperatures up to 260 °C, liners made of PEEK are utilized10. All of these plastic materials are significantly more flexible with high impact resistance compared to traditional GRE liners. The installation process of those internal liner technologies should be done in the shop, as they cannot be done in the field. Therefore, an in situ lining system for downhole tubing is a most needed area of research to minimize the logistics and save operation time.

Downhole Completions

Most downhole completion systems were developed based on the use of metallics. For instance, metallic sand screen systems offer a simple and economic method for controlling sand. These systems have been subject to erosion/corrosion issues, and accordingly limit the life expectancy of the metallic screen. Therefore, ceramic sand screens were developed and proven to deliver high performance sand control in a variety of applications, Fig. 9. Consequently, the polymer composite sand screen is being investigated as an alternative, cost-effective, attractive technology to metallic and ceramic screens. For example, GRE sand screens are an attractive al-ternative to metallic screens. Although, they are still limited to low temperature wells — below 93 °C. On-going efforts are being made to expand the operation envelope of composite sand screen systems, by evaluating alternative advanced plastic materials that withstand high temperatures in oil and gas wells. This would be a breakthrough technology that can resist corrosion/erosion issues faced by conventional sand screens, and it will pave the way for other applications in downhole completion systems, such as inflow control devices and inflow control valves. The dissolvable and drillable composite tools were designed to provide zonal isolation in the wellbore be-tween multistage stimulation treatments.

For instance, the composite frac plugs help to mitigate the risk during drill out, while decreasing time on location and costs to complete unconventional wells. These plugs provide faster mill times than a traditional plug. The R&D efforts are very promising in the area of dissolvable materials that can hold high pressures during the completion operations and retrieval operations2. The elastomer materials have found a niche downhole application in the form of seal

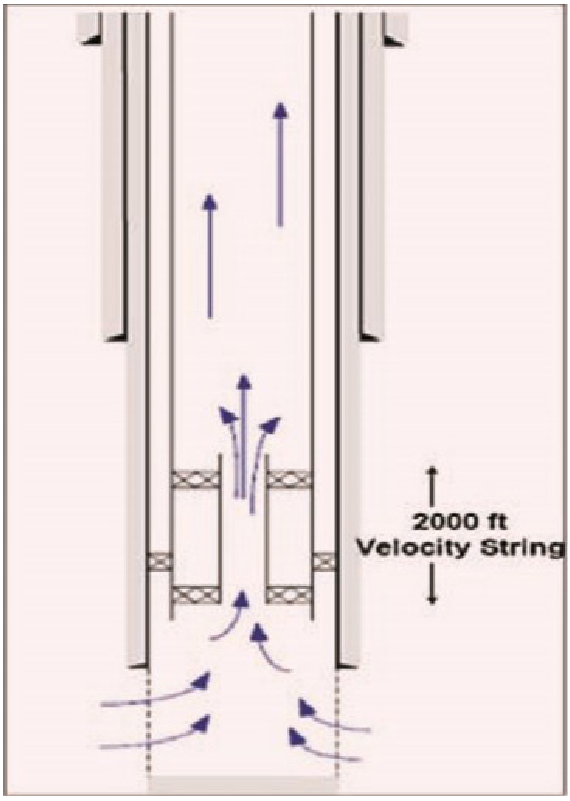


Fig. 7 A schematic of the velocity string equipment9.

elements. Typical elastomer downhole applications include blow out preventers, seals, packers, O-rings and seals for valves, and power sections for downhole motors. It is well-known that the popular use of elastomers in packers for well completion and zonal isolation sealing mechanisms perform a very critical function — either for short-term or long-term performance. For example, swellable packer technology has been steadily gaining momentum.

This technology relies on the physical swelling process characteristic of elastomers. The elastomer can be specifically formulated to achieve a controlled swelling when exposed to hydrocarbons, water, or a combination of both — hybrid swelling packers. The more demanding applications in ultra HPHT with very high H_2S and CO_2 levels are pushing the boundaries of elastomers. Although intensive research and development, as well as qualification, is moving in this area where a combination of elastomers like perfluoro elastomers and engineering plastics such as PEEK and polyamides are gaining momentum. More research is required to keep up with the demands of the ultra HPHT environment.

The utilization of composites in downhole completions is a most needed area of research through the joint efforts between academia, operators, and service companies to improve well integrity, and reduce the weight of the overall completion systems.

Well Intervention Tools

Conventional well intervention tools, such as steel CT and wirelines, have shown several issues with pitting corrosion12. In addition, they are being subjected to high friction within the formation, which limits the ability of the CT to reach down to the target depth. To address potential premature failures, a composite CT was recently introduced in the well intervention business as a low fatigue and corrosion resistant alternative to steel CT, however, due to the inherent limitation of material properties and the product's capabilities to comply with an extended reach requirement, applications of the basic design of composite CT were not found successful. As a result, with the advent of new composite design materials, the CT based on thermoplastic composites are still under development13. The spoolable composite CT may have a structure similar to a TCP with a well bonded structure, or a RTP with an unbonded structure. In these new structure designs, carbon and aramid fiber reinforcement were used in a multilayer configuration that optimized the axial performance and fatigue life of the material, while keeping spoolability and use in a horizontal extended reach well feasible. On the other hand, the composite wireline is also under proof of concept studies, to replace conventional metallic lines. This would be a breakthrough technology in the oil and gas industry. Although, the initial cost of thermoplastic composite well intervention technology is high, there are

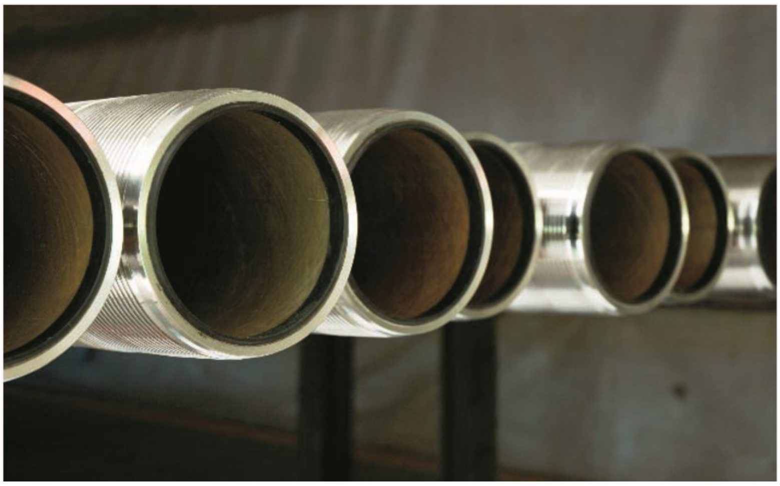


Fig. 8 GRE lining of carbon steel production tubing.

many advantages that may help in the reduction of the operational cost by increasing resistance to corrosion, ease of handling in a severe dogleg, providing less friction, it is lightweight, and has better mechanical properties.

Casing Flex Shoe

A composite flexible shoe can be a good solution when running casing with a high build rate and inclination, to minimize the risk of getting stuck off bottom, Fig. 1014. The flexible casing shoe reduces the side loads at the bottom of the drill string when running into the hole. Due to the flexibility of nonmetallic composites, as compared to steel, it minimizes the high loads resulting from the inherent stiffness of the metallic casing, as it is bent through doglegs downhole. The product provides many advantages in tackling wellbore challenges, including:

- The ability to guide large diameter casings with inclinations above 40°.
- Use with any size casing when running through severe doglegs
- Use with deep-water wells, which require the use of stiff, large diameter casings.
- Use in extended reach drilling or horizontal wells to prevent buckling or hanging up casing in the build and lateral sections, to increase run efficiency.

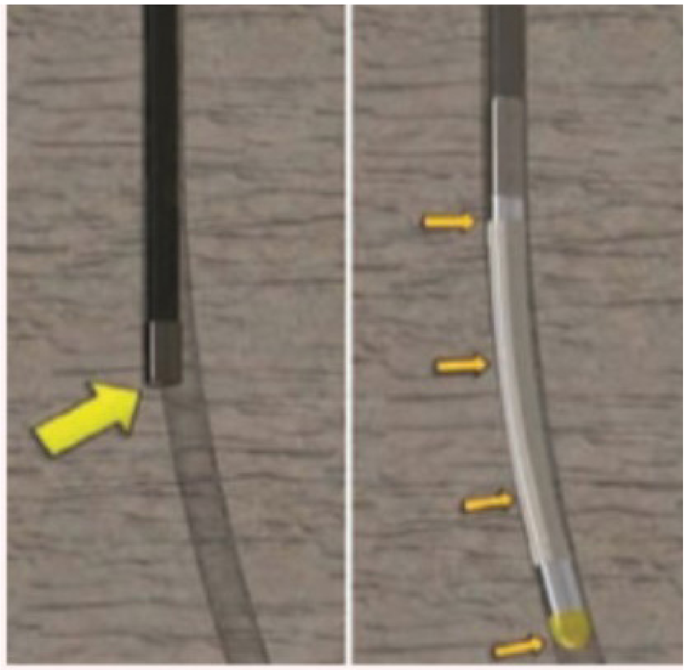
Impeller Pump

A conventional metallic impeller/diffuser for downhole electric submersible pumps (ESP) is subjected to frequent failure due to high corrosive environments. For ESP impellers in oil and gas applications, particle erosion/

Fig. 9 Ceramic sand screen design[11].

Fig. 10 *Composite casing flex shoe*[14]

corrosion is the main cause of the component failures in the process lines. Engineered composite pumps have proven to outlast metallic parts by many years, because composite pumps better resist cavitation, and they are not subject to corrosion or electrolysis attack. Composite pumps have become a solution for longer pump life, Fig. 11. The structure of composite pump materials includes graphite composite made of 3D graphite interwoven fibers with a hybrid phenolic resin system. The composite impeller pumps are capable of continuous operation at 150 °C, and have excellent mechanical properties and chemical resistance15. Currently, there is a business need in deploying this technology to resolve the premature erosion/corrosion effects. As result, a feasibility study is in process to ensure that the full composite impeller is a reliable technology, able to withstand downhole well conditions.



Shape Memory Polymer (SMP)

The shape memory polymer (SMP) is a smart material that changes its properties in response to external stim-ulus. There are different triggering mechanisms that the SMP responds to, such as temperature and chemical reactions. For instance, the SMP polyurethane (SMPU) foam has several potential applications in downhole zonal isolations, including water shut off for downhole fracture operations.

The activation of the SMP expansion occurs if the surrounding temperature is higher than the high glass transition temperature of the SMP. Otherwise, no activation occurs. Recently, the SMPU has been used as a reactive sand control media to control the sand in open hole ap-plications, replacing the conventional open hole gravel packing. The SMP was designed to be run in the hole as part of the completion in a compressed state with an outer diameter smaller than that of the wellbore when activated. The SMP material then expands and fills the entire annulus, applying residual stress to the sandface while acting as a filtration medium16. This application has proven the effectiveness of SMP foam to eliminate the concerns of plugging and erosion associated with a stand-alone screen16. The sand management was selected as an initial application, which will pave the way for several applications for SMPs in downhole use.

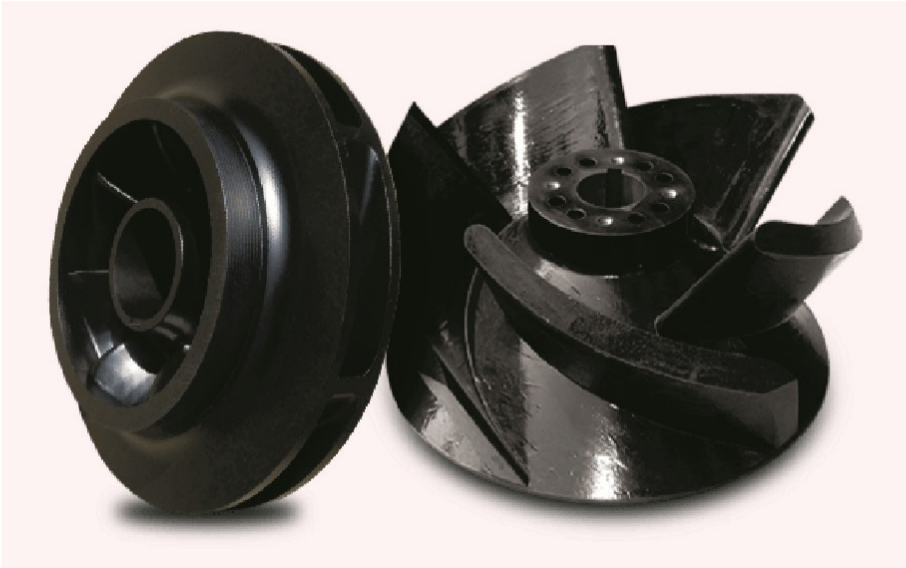


Fig. 11 Nonmetallic composite pump impeller[15].

Path Forward

Nonmetallic composites have many advantages in terms of corrosion resistance and extension of the well's life cycle; however, the high initial cost and limitation of technical skills present substantial challenges. The worldwide oil industry has observed the business need for allocating the necessary investment needed in R&D to support utilizing nonmetallics in downhole applications. Otherwise, the investment and localization of nonmetallics are other important pillars that would help to reduce the initial cost and improve local technical skills. The path forward is clearly articulated around the role of the end user, R&D entities, and service companies to serve the industry.

The following are some initiatives toward optimizing nonmetallic composite expertise in downhole applications:

- Support for the R&D is needed to replace the conventional tubing/casing with nonmetallic composite materials in water application wells, which includes supply, disposal, injection, and observation wells.
- Expand the operating envelope of current composite materials.
- Explore organic and natural materials that would help reduce the cost of the carbon fiber.
- Optimize the cost of composite raw material and the manufacturing process.
- Introduce 3D printing technology in the composite manufacturing process.
- Develop a nondestructive evaluation for online inspec-tion of the composite structure and induced defects.
- Study the mechanical behavior of composites and material degradation based on high temperature and loading/deformation.
- Develop the numerical models supporting composite material selection and life prediction based on downhole conditions.
- Develop nonmetallic standards supporting downhole applications.
- Expand the applications of spoolable composites, i.e., RTP concept, to be used for downhole tubing.
- Explore alternative applications beyond tubulars, including completion, well intervention, and ESP applications.
- Address different associated challenges related to packer setting, cementing, perforation, and completion installation with full nonmetallic tubulars.
- Support the research and validation of new materials for swellable packers in ultra-HPHT wells.
- Develop a reliable threaded connection for metal composite joints that withstand high pressures.
- Develop smart materials such as SMP for downhole zonal isolations.
- Support the localization and an investment plan in the composite business.
- Develop the intelligent composite tubing, where fiber optic sensing and the power cable can be embedded for downhole real-time measurements.

Conclusions

Nonmetallic composite-based materials have been introduced in oil and gas applications, including onshore, offshore, and downhole. As clearly stated in this article, the deployment of nonmetallic materials in downhole applications has allowed us to overcome corrosion challenges, minimize frequent workover, and extend the life cycle of critical downhole products, including tubular, drilling, and well completions. As a result, much effort by the industry has placed a heavy emphasis on robust deployment and development methodologies in alignment with the field application trends to qualify cost-effective composite materials covering many downhole applications. The path forward, which already started in R&D, is focused toward improving the composite business to serve the oil and gas industry. This involves the development of specific roadmaps for different products to accelerate the mass deployment, support localization and investment in research studies. This effort requires joint work with different entities that sets the basis for increasing the deployment of cost-effective materials for more demanding HPHT applications.

Acknowledgments

The authors would like to thank the management of Saudi Aramco for their support and permission to pub-lish this article.

This article was accepted for presentation at the Gas and Oil Technology Showcase and Conference, Abu Dhabi, UAE, October 21-23, 2019.

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Dr. Mohamed N. Noui-Mehidi is Senior Petroleum Engineer Consultant at Saudi Aramco's Exploration and Petroleum Engineering Center – Advanced Research Center (EXPEC ARC). He is the Advanced Well Systems focus area champion for the Production Technology Team. Mohamed joined Saudi Aramco in late 2008 after previously working for the Commonwealth Scientific and Industrial Research Organization, Australia. He has more than 29 years of experience in the area of multiphase flow dynamics, flow metering, and flow modeling. Mohamed's research activities are in the development of new technologies in well control and monitoring for upstream oil and gas production, well intervention tools, and flow sensors. He has published more than 100 journal articles and conference papers on the different aspects of fundamental and applied fluid dynamics as well as authored 39 company granted patents and several patent applications. Mohamed received his Ph.D. degree in Resource & Energy Science from the University of Kobe, Kobe, Japan.

Oscar D. Salazar

M.S. degree in Polymer Science, University of Akron

Oscar D. Salazar is a Nonmetallic Engineering Specialist working in the Nonmetallic Engineering Division of Saudi Aramco's Consulting Services Department. Prior to joining Saudi Aramco, he worked in Weatherford International where he was in charge of research, product development, and lab qualification of nonmetallic materials for downhole applications, including composites, elastomers, and coatings. Oscar also worked as an independent consultant in nonmetallic materials in several projects for Total and Conoco. His work experience extends to 25 years in nonmetallic and coatings, covering a broad spectrum of activities such as design of experiments, failure analysis, development of engineering standards, materials selection and research and development. Oscar received his M.S. degree in Polymer Science from the University of Akron, Akron, Ohio. In addition, he has academic experience in root cause analysis through courses at the university level.

In Memoriam Abdul Majid Rasheed

Abdul Majid Rasheed passed away earlier this year. Majid was International Editor for EPRasheed and during this period he interviewed senior executives including ex CEO and President of Petrobras Gabrielli of Petrobras and Bertrand President Operations of PetroTrin. Majid paid great attention to detail and had an extensive knowledge of the industry. Majid is survived by four children Abdur Raheem, Selina, Zaynab and Ibraheem.

CALL FOR ABSTRACTS

Artificially Intelligent Earth Exploration Workshop:
Teaching the Machine How to Characterize the Subsurface

19–21 April 2020 | Muscat, Oman

CALL FOR ABSTRACTS

CLOSES 20 JANUARY 2020

Please e-mail the abstract and the call for abstracts form to **aklerk@seg.org** or fax to **+971 4 372 4204**

REGISTRATION

OPENS 28 NOVEMBER 2019

REGISTER EARLY AND SAVE BY 18 MARCH 2020

WORKSHOP DESCRIPTION

Artificial intelligence, and specifically machine learning, has become a powerful tool to address many of the challenges we face as we try to illuminate the Earth and make the proper prediction of its content. From image resolution enhancements, to fault detection, to salt boundary picking, the quest to teach our computing devices how to perform these tasks efficiently and accurately, as well as quantify the accuracy, has become a feasible and sought-after objective. Recent advances in computer power, machine learning algorithms, and the availability of the modules to apply such algorithms, have allowed the geoscientist to focus on the potential applications of such tools. The objective of this workshop is to bring together interested individuals to share their experiences in applying machine learning algorithms in geoscience applications, especially applications related to the Oil and Gas sector.

What can we teach the machine, what can't we teach it, and more importantly, what can it teach us?

SELECTION FRAMEWORK

We would like you to share your machine learning experience, encompassing the following:

- Data acquisition, pre-processing and classification?
- Training data construction and labelling?
- Choice of algorithm and architecture (the parameters)?
- Constraints from physics based and classical methods?
- Evaluation, validation procedures and uncertainty analysis?
- Added value from ML: efficiency, accuracy etc.?
- What is next? The future?

ABSTRACT SUBJECTS

The workshop invites contributions in all related subjects that utilize machine learning to solve geophysical data analysis challenges in the Oil and Gas sector, topics include:

- Interpretation and picking
- 4D seismics and data matching
- Reservoir characterization and seismic inversion
- Data and wavefield interpolation and extrapolation
- Image enhancements and improved resolution
- Definition of salt bodies and other subsurface features
- Velocity analysis and inversion
- Data processing automation and acceleration
- Geophysical data integration
- Reservoir geomechanics
- Well logging and formation evaluation

ABSTRACT FORMAT

Max 2 page abstract + 1 figure, single column

Abstracts should include sufficient details for the committee to judge the quality of the submitted work. Abstracts should be a minimum of 1 page, text plus 1 figure, with a maximum of 2 pages. Abstracts should be on 8.5 x 11 inch paper size, text in Roman font, and include both text and figures. Title should be one or two lines, at the top of the page, in bold font, and size 12 point. Authors should be listed in Roman italic font, size 10 point, and located just below the title. All text must stay 1 inch clear of the margins of the page. Submissions should be in Adobe Acrobat PDF format.

PRINT IN BLACK INK OR TYPE

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Subject ____________________ Presentation Type: Oral Poster Both

NOTE: The mechanical recording of any portion of the SEG workshop in any form (photographic, electronic, etc.) is strictly prohibited. Printed reference to the workshop presentations or discussions is not permitted without the consent of the parties involved. All participants are requested to omit public reference to the workshop proceedings in any published work or oral presentation. Only registrants are permitted to attend workshop sessions. Each participant agrees to these regulations when application is accepted, as indicated by his or her signature on this form.

Signature: ____________________ Date: ____________________

Please email abstract and call for abstracts form by **20 JANUARY 2020** to **aklerk@seg.org** or fax to **+971 4 372 4204**.

ORGANIZING COMMITTEE

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